FAST OPTICAL SHUTTER

FIELD OF INVENTION

The present invention relates generally to liquid crystal
optical shutters that are to be operated with high electrical
voltages and more specifically to a large sized, high voltage
optical shutter using cholesteric liquid crystal materials.

BACKGROUND OF THE INVENTION

A wide range of different types of optical shutters have been
developed over the years. An optical shutter can in general be
switched between two or more optical states upon application
of an externally applied electric field. The different optical
states possess different optical properties in terms of
transmission, reflection and absorption.

An optical shutter according to the state of the art typically
possesses an active area or aperture window consisting of one
large picture element or "pixel" that can be turned ON or OFF,
i.e. either being reflective or transparent. However, compared
to liquid crystal displays (LCD's), for example, an optical
shutter possesses a comparatively large aperture window; aper-
ture windows as large as 400mm * 400mm are not uncommon.

One type of optical shutter known to the art uses cholesteric
liquid crystal materials. Here, the cholesteric liquid
crystals can be electronically switched between a high light
scattering state, referred to as the focal conic texture, and
a transparent state, referred to as the homeotropic phase.
Moreover, one technique known to the art results in the chole-
steric liquid crystal optical shutter being highly transparent
when activated with an applied voltage, and being highly light
scattering when the voltage is removed.

Prior art discloses that a cholesteric liquid crystal optical shutter typically consists of two parallel planar substrates. The inner surfaces of the substrates are often coated with an electrically conducting thin layer or electrode, which is also predominantly optically transparent. Moreover, the electrodes are often coated with one or more insulation layers or hard coat layers in order to minimise the flow of electricity between said substrates. There may or may not also be an additional thin layer coating on top of the insulation layers in order to induce the required molecular alignment of the liquid crystal material at the surfaces of the two substrates.

The distance gap between the substrates is often controlled by the placing of small distance spheres or spacers between said substrates. The diameter of the spacers are accurately controlled, hence a precise and homogeneous cell gap is obtained. Furthermore, in order to obtain a high level of optical light scattering when in the focal conic texture, it is often necessary to use a large cell gap for a cholesteric liquid crystal optical shutter. Typical cell gaps of between 10 and 30 micrometers are often used.

The liquid crystal material is bounded between the two parallel substrates. When a voltage is applied to the contact surface of each electrode on each side of the cell, voltage acts on the liquid crystal material localised in the regions where said conducting layers on each side of the cell mutually overlap, hence switching the liquid crystal material in said regions to the required optical state. It is therefore the overlap regions between the two conducting layers on each side of the cell that make up the active area or aperture window of the optical shutter.

The switching speed of an optical shutter is defined as being the time taken for the optical shutter to change from one

optical state to another. In many applications, a quick
switching speed is required in order to rapidly modulate the
passage of light through the optical device. Furthermore, it
is known to one skilled in the art that fast switching speeds
can be obtained by using high electrical fields to operate the
liquid crystal material.

For example, an electric field strength of over 12 volts per
micrometer can be used to rapidly switch a cholesteric liquid
crystal optical shutter from the light scattering, focal conic
texture, to the highly transparent homeotropic state. With a
cholesteric liquid crystal optical shutter possessing a cell
thickness of 20 micrometers, an externally applied voltage of
over 240 volts hence is required. It is therefore often
necessary to operate cholesteric liquid crystal optical
shutters with ultra high voltages in order to attain the
required speed in switching response.

Prior art discloses that the aperture window of a cholesteric
liquid crystal optical shutter is often in the form of, but
not limited to, a rectangle or oval. Such geometry of the
electrodes on each side of the cell results in there being a
low electrical resistance within the conducting layer of each
substrate. For example, with an optical shutter possessing a
square aperture window and using as the electrode material an
indium-doped tin oxide (ITO) thin film possessing an intrinsic
sheet resistance of 10 ohms per square, the total overall
electrical resistance of each substrate will be only 10 ohms.

Figs. 1a-c show the geometry of the electrodes employed in an
optical shutter possessing a rectangular shaped aperture
window according to the state of the art. Fig. 1a shows a
first generally planar side or substrate plate 10 having a
first electrode 12 provided thereon, whilst fig. 1b shows a
second generally planar side or substrate plate 20 having a

second electrode 22 provided thereon. The substrates 10, 20
are arranged at a uniform mutual distance and liquid crystal
material in the form of cholesteric liquid crystals (for the
sake of clarity not shown in figs. 1a-c) is provided between
the two plates 10 and 20. The mutual overlap 24 of the
electrodes defines the aperture window.

Here, the low electrical resistance associated with the
geometry of the electrodes on each side of the cell permits a
high leakage current to flow through any defect spots present
in the insulation layers, hence allowing for the occurrence of
electrical break-down. A defect spot in one or more of the
insulation layers in the liquid crystal cell such as, for
example but not limited to, a pin-hole, crack or contaminant
particle, may result in some electrical leakage current occur-
ring at said defect point between the two cell substrates.
Moreover, the low overall electrical resistance of the con-
ducting layer on each substrate associated with the geometry
of a rectangular or oval type aperture window according to 'the
state of the art, results in there being little electrical
resistance in series with the defect in order to limit the
current leakage through said defect point. This current leak-
age and the associated local thermal heating of the defect
spot may in turn lead to the occurrence of electrical sparking
between the two substrates. Such electrical sparking may
result in the formation of a burn-mark within the liquid
crystal cell, visible as an optical defect.

The low overall electrical resistance of the conducting layers
on both sides of the cell due to the geometry of the aperture
window in a state of the art cholesteric liquid crystal opti-
cal shutter, together with the ultra high voltage required in
order to attain adequate switching speeds, results in there
being a high risk for the occurrence of electrical sparking

between said substrates. This places a very high demand on the
manufacturing quality of a cholesteric liquid crystal optical
shutter. In particular, it is known to one skilled in the art
that the number of defect spots present in the insulation
layers covering the two electrodes on the substrates of the
liquid crystal cell should be reduced to a minimum.

Furthermore, as the size or area of the optical shutter in-
creases, there is an increased risk that such defects occur
due to manufacturing tolerances. It has therefore proved
difficult to manufacture large sized, cholesteric liquid
crystal optical shutters using state of the art electrode
designs that are to be operated with high voltages.

Prior art describes one technique that can be used to reduce
the risk of occurrence of electrical sparking within a chole-
steric liquid crystal optical shutter, whereby either extra-
thick insulation layers or several stacked layers of insu-
lation coatings are applied to the inner surfaces of both
sides of the cell. However, such cell designs are complicated
to manufacture and significantly increase manufacturing costs.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a liquid
crystal optical shutter possessing a large area aperture
window, which is designed so that the optical shutter can be
operated with high voltages without electrical sparking
occurring between the two cell substrates.

The invention is based on the insight that by changing the
geometry of the conducting layers or electrodes on the inner
surfaces of the two substrates of the cell, the internal
electrical resistance in series with any given defect spot can
be significantly increased and moreover is also homogenous
over the entire surface area of the aperture window. This

series resistance limits the leakage current which is able to
flow through the defect spot and hence prevents electrical
sparking from occurring.

Furthermore, the geometry of the conducting layers is designed
so that the total overall resistance of the liquid crystal
cell as a whole remains low. This is an important criterion in
order to allow for the rapid electrical capacitive charge and
discharge of the liquid crystal cell and hence allow for fast
optical shutter switching speeds.

According to the invention there is provided a liquid crystal
optical shutter according to claim 1. Thus, there is provided
an optical shutter wherein first and second electrode patterns
each comprises a series of essentially parallel row
electrodes, wherein the series of row electrodes of the first
electrode pattern are aligned at an angle of less than 45
degrees with the series of row electrodes of the second
electrode pattern, so as to create a high internal electrical
resistance in series with any point in the liquid crystal
optical shutter, whilst also maintaining the overall external
resistance of the optical shutter at a low level.

With the inventive optical shutter, the drawbacks of prior art
optical shutters are avoided or at least mitigated. By using
the inventive idea, large sized liquid crystal optical shut-
ters can be designed such that the occurrence of electrical
sparking is significantly reduced.

Moreover, by designing the conducting layers so that the total
overall resistance of the liquid crystal cell as a whole
remains low, the rapid electrical capacitive charge and
discharge of the liquid crystal cell is permitted, hence
allowing for a fast optical shutter switching speeds.

In a preferred embodiment, the series of row electrodes of the first electrode pattern are aligned at an angle of less than 25 degrees, preferably less than 10 degrees, and most preferably essentially parallel with the series of row electrodes of the second electrode pattern.

In a further preferred embodiment, the maximum distance between adjacent regions of the electrode patterning on a given substrate surface is kept below a critical distance. This enables the fringe voltage at the edges of the electrodes to simultaneously activate the liquid crystal material bounded in the gap regions between the electrode patterning structure. The activation of the liquid crystal material in said gap regions prevents the electrode patterning layout from being visually apparent in the optical shutter.

Further preferred embodiments are defined in the dependent claims herein.

BRIEF DESCRIPTIONS OF THE DRAWINGS

The invention is now described, by way of example, with refer-ence to the accompanying drawings, in which:

Figures 1a and 1b show the electrode geometry on the respec-tive sides of the cell for an optical shutter possessing a rectangular aperture window according to the state of the art;

Figure 1c shows the combined electrode geometry in the comp-lete liquid crystal cell for the two sides shown in figures 1a and 1b;

Figures 2a and 2b show the electrode geometry on the respec-tive sides of the cell for an optical shutter according to an embodiment of the present invention;

Figure 2c shows the combined electrode geometry in the com-
plete liquid crystal cell for the two sides shown in figures
2a and 2b;

Figure 3 is a sectional view of an optical shutter according
to the invention showing the fringe voltage at the edges of
the rows in the electrode pattern;

Figure 4 is a sectional view of an alternative embodiment of
an optical shutter according to the invention;

Figures 5a and 5b show the electrode geometry on the respec-
tive sides of the cell for an optical shutter according to an
alternative embodiment of the present invention; and

Figure 5c shows the combined electrode geometry in the com-
plete liquid crystal cell for the two sides shown in figures
5a and 5b.

DETAILED DESCRIPTION OF THE INVENTION

Figs. 1a-c have been discussed in connection with prior art
and will therefore not be dealt with further.

Figs. 2 show an electrode geometry patterning in an optical
shutter possessing a rectangular shaped aperture window
according to an embodiment of the present invention. Fig. 2a
shows a first generally planar side or substrate plate 110
having a first electrode pattern 112 provided thereon, whilst
fig. 2b shows a second generally planar side or substrate
plate 120 having a second electrode pattern 122 provided
thereon. The substrates 110, 120 are arranged at a uniform
mutual distance d, see fig. 3, and liquid crystal material in
the form of cholesteric liquid crystals (for the sake of
clarity not shown in the figures) is provided between the two
plates 110 and 120.

The first electrode pattern 112 comprises a series of geometrically linear and mutually parallel rows 112a-g of electrode material with constant thickness. The series of rows are electrically connected in parallel with each other by all rows being connected directly to the same first contact surface 112h at one end of the substrate, hence the same electrical voltage is applied to all rows simultaneously. Here, the rows are electrically connected in parallel with each other internally on the substrate surface.

The second electrode pattern 122 is a mirror image of the first electrode pattern, comprising a series of rows 122a-g electrically connected in parallel with each other by means of a second contact surface 122h located along an edge of the substrate 120 opposite from the edge where the first contact surface is located.

The rows of the first electrode pattern 112 are aligned essentially in parallel with and overlapping the rows of the second electrode pattern 122.

The mutual overlap of the electrodes defines the rectangular shaped aperture window 124. As is evident from fig. 2c, the aperture window consists of a series of parallel electrode rows on each side of the cell. Moreover, the two sets of rows on the two substrates of the cell are oriented such that they are predominantly mutually parallel.

Due to the electrode patterning structure, there is a high internal electrical resistance in series with any given defect point that may be present in the insulation layers of the liquid crystal cell. The high series resistance limits the magnitude of the leakage current able to flow through said defect point, hence mitigating the occurrence of electrical break-down.

Moreover, the aperture window according to the present invention ensures that the electrical resistance in series with a given defect point is exactly the same over the entire surface area of the aperture window, independent of the location of the defect spot in the liquid crystal cell.

Furthermore, the fringe voltage at the edges of each row are perturbed and extend a certain distance into the gap regions between the rows, shown in fig. 3, which is a detailed cross sectional view of the aperture window of fig. 2c. In fig. 3 there is shown the first 110 and second 120 substrate plates having electrode rows 112a, 112b and 122a, 122b, respectively, provided on the inner surfaces. Voltage fields 126a, 126b are shown in the figure extending between the first and second electrode rows. At the edges of the row electrodes, the voltage field is slightly curved or perturbed, forming a so-called fringe voltage that extends outside of the edges of the electrodes.

It is known to one skilled in the art that the extension distance of the fringe voltage is given as being approximately twice the cell gap distance, shown as distance "d" in figs. 3 and 4. For example, with a cell gap of 20 micrometers, the fringe voltage will extend approximately 40 micrometers into the gap regions between the edges of the different row electrodes.

It is preferred that the maximum distance g, see fig. 3, between two adjacent rows on a given substrate is kept below the distance at which the fringe electric field extends into the gap region. This ensures that the voltage applied to the electrodes on each side of the cell activate not only the liquid crystal material bounded by the mutual overlap of the rows on either side of the cell, but also the liquid crystal material localised in the gap regions between said rows. This

ensures that the electrode patterning on both sides of the cell is not visually apparent in the complete optical shutter.

The total overall resistance of the complete liquid crystal cell as a whole remains low when using the disclosed geometric electrode structure. This ensures that the electrical capacitive charging and discharging times for the liquid crystal optical shutter are minimised, hence allowing for a fast switching response between the optical states.

For example, with an optical shutter possessing a rectangular shaped aperture window of length L and width W, consisting of a series of linear and mutually parallel rows according to an embodiment of the present invention of thickness T and employing as the electrode material a transparent conducting thin film with an intrinsic sheet resistance of R, the total electrical resistance of each electrode row on a given substrate will be (L*R/T). This will be the total electrical resistance in series with any given defect spot that may be present in the insulation layers of the liquid crystal cell and will limit the leakage current able to flow through said defect spot, hence preventing the occurrence of electrical sparking. Furthermore, the total number of rows making up the aperture window of the optical shutter is given by (W/T).

Assuming that the gaps between the rows are negligible, the total resistance of each substrate surface in the liquid crystal optical shutter is found by summating together all row resistances connected in parallel, given by 1/(T/L*R)*(W/T) = (L/W)*R. It is known to one skilled in the art that this result is exactly the same overall total resistance that the substrates in an optical shutter possessing an unpatterned rectangular aperture window consisting of a single rectangular pixel would have according to prior art. The total overall resistance of the optical shutter possessing an aperture

window according to the present invention is therefore
identical to that for an optical shutter that possesses an
unpatterned, single-pixel aperture window according to the
state of the art and hence the total resistance of the cell is
maintained at a low level in order to enable for the rapid
electrical capacitive charging and discharging of the liquid
crystal cell.

More specifically, for a cholesteric liquid crystal optical
shutter with dimensions of 400mm * 400mm using the disclosed
electrode design consisting of electrode rows of width 0.1mm
and using an electrode material possessing an intrinsic sheet
resistance of 100 ohms per square, the total resistance of
each row is given by $(L*R)/T = 0.4$ MΩ. It is this internal
resistance that is in series with any given defect spot in the
cell and hence limits the current that can flow through said
defect spot. Furthermore, the total resistance of each
substrate surface in the complete liquid crystal optical
shutter as a whole is given by $(L/W)*R = 100$ ohms.

Moreover, if the cell gap is 20 micrometers and the gaps
between the rows on each substrate is less than approximately
40 micrometers, then the fringe voltage will activate the
liquid crystal material in the gap regions and consequently
the electrode patterning will not be visually apparent in the
complete optical shutter.

An alternative embodiment of an optical shutter according to
the invention is shown in fig. 4. As with the first embodiment
described with reference to figs. 2a-c and 3, this second
embodiment of an optical shutter comprises a first generally
planar side or substrate plate 210 having a first electrode
pattern 212 provided thereon and a second generally planar
side or substrate plate 220 having a second electrode pattern
222 provided thereon.

However, in this second embodiment the electrode rows 212a, b
of the first electrode pattern are positioned so that they
overlap the electrode gaps of the second electrode pattern.
The resulting lateral voltage field will help to activate the
liquid crystal material in the gap regions and hence ensure
that the electrode patterning is not visually apparent in the
optical shutter.

Prior art discloses the passive matrix liquid crystal display.
Here, there exists a series of electrode rows on one side of
the liquid crystal cell and a series of electrode columns on
the other side of said cell. The rows and columns are oriented
predominantly perpendicular to each other and the mutual
overlap of a row on one side of the cell with a column on the
other side of said cell defines a picture element or pixel in
the liquid crystal display. Voltage is applied independently
to each row and each column separately and an image is scanned
into the display row-by-row.

The electrode patterning of a liquid crystal optical shutter
according to the present invention differs from the design of
the state of the art passive matrix display in that the two
sets of electrode rows on the two substrate surfaces in the
liquid crystal cell are oriented predominantly parallel with
each other. Moreover, the series of rows on each side of the
cell are electrically connected in parallel so that the same
electrical voltage is applied to all rows simultaneously.

In the embodiment described with reference to figs. 2a-c, the
row electrodes have been generally straight. However, in an
alternative embodiment shown in figs. 5a-c, the individual row
electrodes of the electrode patterns have a zigzag shape.
Thus, the first electrode pattern 312 comprises a series of
zigzag shaped but still mutually parallel rows 312a-d of
electrode material with constant thickness. The series of rows

are electrically connected in parallel with each other by all rows being connected directly to the same first contact surface at one end of the substrate, hence the same electrical voltage is applied to all rows simultaneously.

The second electrode pattern 322 is a mirror image of the first electrode pattern, comprising a series of rows 322a-d electrically connected in parallel with each other by means of a second contact surface 322e located along an edge of the substrate 320 opposite from the edge where the first contact surface is located.

Although the overall geometrical shape of the rows of the first and second electrode patterns 312, 322 are straight and essentially mutually parallel as in the first embodiment shown in figs. 2a-c, they locally intersect each other at a relatively high angle, illustrated in fig. 5c. This configuration once again provides for a high and homogeneous internal electrical resistance in series with any defect spots that may be present in the liquid crystal cell, whilst maintaining the overall external resistance of the cell at a low level.

Whilst preferred embodiments have been shown and described herein, various modifications may be made thereto without departing from the inventive idea of the present invention. Accordingly, it is to be understood that the present invention has been described by way of illustration and not limitation.

Cholesteric liquid crystals have been described together with the optical shutter according to the invention. However, any liquid crystals exhibiting similar characteristics as chole-steric liquid crystals can be used with the present invention.

It will be obvious to one skilled in the art that other liquid crystal cell optical shutter constructions are also possible

that allow for a high internal series resistance to be pro-
vided for by patterning of the electrodes on the inner sur-
faces of each substrate in the liquid crystal cell. For exam-
ple, the two sets of electrode rows on the two substrate sur-
faces may be oriented such that there exists a small inter-
section angle between said sets of rows. This mutual inter-
section angle could be as high as 45 degrees, although an
intersection angle of less than 25 degrees is preferred and an
intersection angle of less than 10 degrees is even more
preferred. However, the preferred embodiment is when the two
sets of rows are essentially mutually parallel, as illustrated
herein. Although a non-zero intersection angle between the two
sets of rows on the two substrate surfaces would not minimise
the overall total electrical resistance of the cell, a high
internal resistance is never-the-less obtained that will help
to mitigate the occurrence of electrical sparking in said
optical shutter.

Furthermore, a rectangular aperture window has been described
herein. It will be appreciated that the aperture window can
also take other geometric shapes as well, such as an oval or
circular shape. This can be obtained by providing non-linear
electrodes, such as curved electrodes. Also, the electrode
rows are not necessarily required to have a uniform and con-
stant width along their entire length and the electrode rows
are not required to all have the same width as each other.

Although the rows of each electrode have been shown to be
electrically connected in parallel internally on each of the
two substrates, they could also be electrically connected in
parallel externally from the substrates by other means.